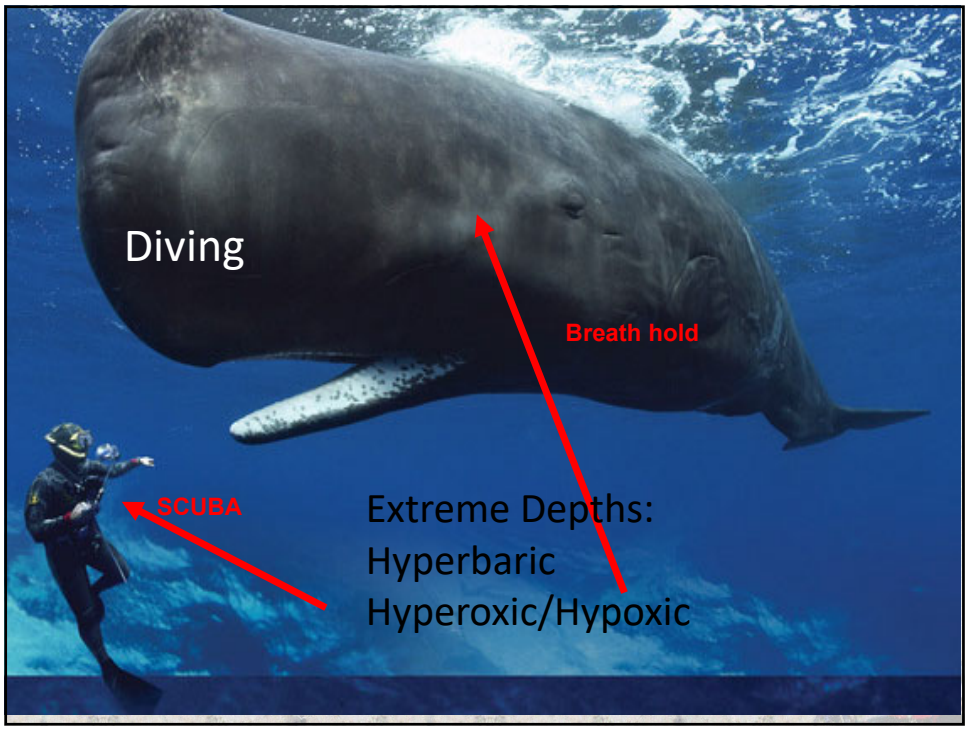



1

## Animals at depth

| Altitude/Depth | Air Pressure (kPa) | $pO_2$ (kPa) | |
|---|---|---|---|
| >20000 m | < 6 | < 1 | Water boils at 20°C |
| 20000 m | 6 | 1 | Only water in lungs |
| 12300 m | 20 | 4 | Pure $O_2$ "ceiling" |
| 8800 m | 34 | 7 | Mt Everest |
| 6200 m | 56 | 12 | Normal $O_2$ "ceiling" |
| 2230 m | 80 | 16 | Mt Kosciuzko |
| **0 m** | **101** | **21** | **Sea level** |
| **-10 m** | **202** | **42** | **101 kPa/10 m water depth** |
| **-40 m** | **505** | **105** | **Bends, chronic $O_2$ toxicity** |
| **-80 m** | **909** | **189** | **$N_2$ narcosis** |
| **-190 m** | **2020** | **420** | **Acute $O_2$ toxicity** |

2

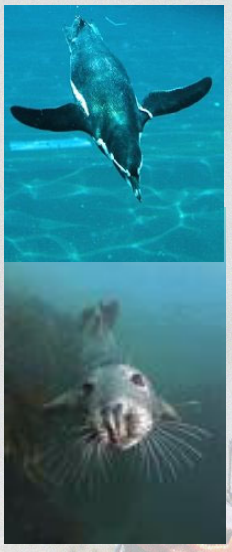
# Diving birds and mammals

Birds and mammals have limited physiological options to adjust to the metabolic, respiratory and circulatory demands of diving.

The DIVING RESPONSE consists of 3 main components:

- Bradycardia (decreased heart rate)
- Decreased cardiac output (to lungs, digestive tract, and limb muscles)
- Anaerobic metabolism (skeletal muscle)

None of these adjustments are unique to diving birds and mammals!



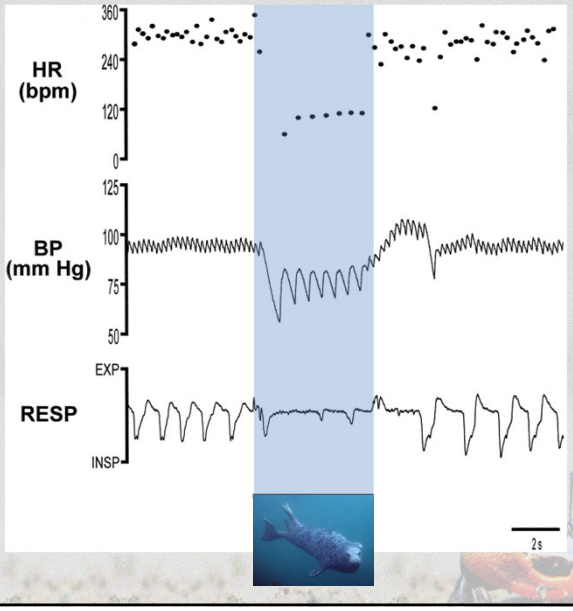
3

# Diving response

Bradycardia

Blood pressure

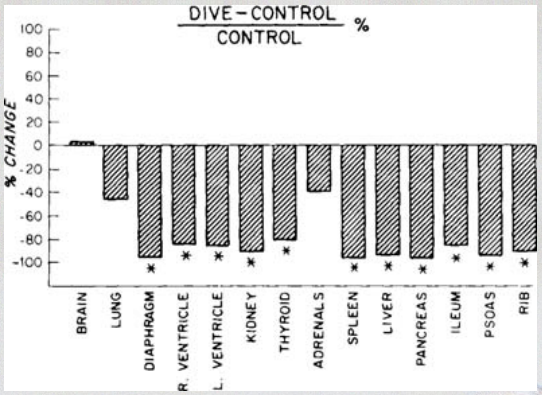
Respiration




4

# Diving response

Peripheral blood flow distribution




5

# Cardiovascular oxygen transport - cardiac output

Cardiac output = heart rate x stroke volume

CO is usually tightly matched to metabolic demand

Decrease in CO is accomplished by decline in

- Heart rate (common, biggest contribution)
- Stroke volume (less common, smaller contribution)

Decrease in CO is matched by peripheral vasoconstriction (to maintain blood pressure)

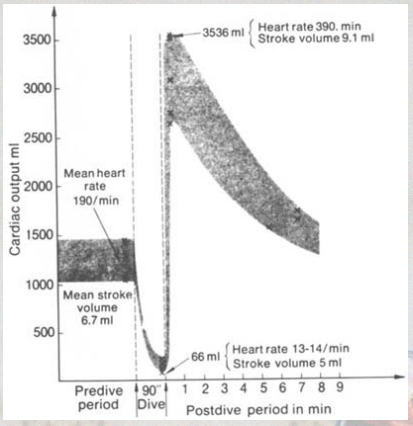
- Primarily arterioles

6

# Diving response

Bradycardia and Cardiac Output (hr x SV)

If heart rate drops then either blood pressure drops or you have marked vasoconstriction somewhere






# Oxygen stores

Oxygen content of the lungs depends on

- lung volume (and whether you have just inspired or expired)

Oxygen content of blood depends

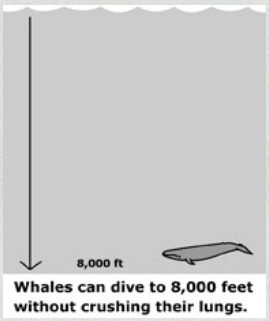
- on $O_2$ carrying capacity (Hb content) (cannot be changed)
- (arterial – venous) $pO_2$

Oxygen content of the muscle depends on

- myoglobin concentration (Mb)
- tissue $pO_2$

# Oxygen stores - lungs

Oxygen content of the lungs depends on
lung volume (inspired or expired)

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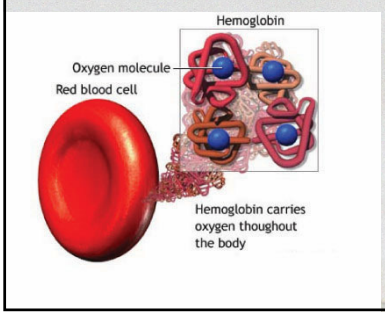
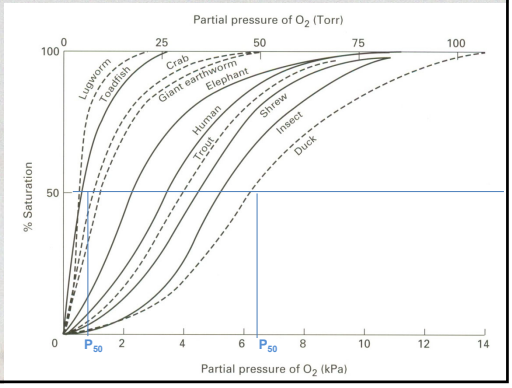
# Oxygen stores - blood

Oxygen content of blood depends on
haemoglobin concentration and $O_2$ carrying capacity

Oxygen content of blood also depends on
- $pO_2$ (in tissue where you want to unload the oxygen)
- $O_2$ dissociation curve

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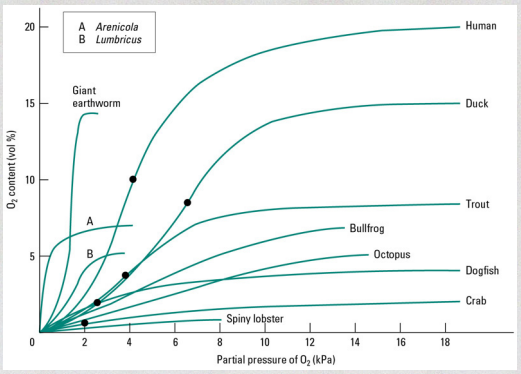
# Oxygen stores - blood

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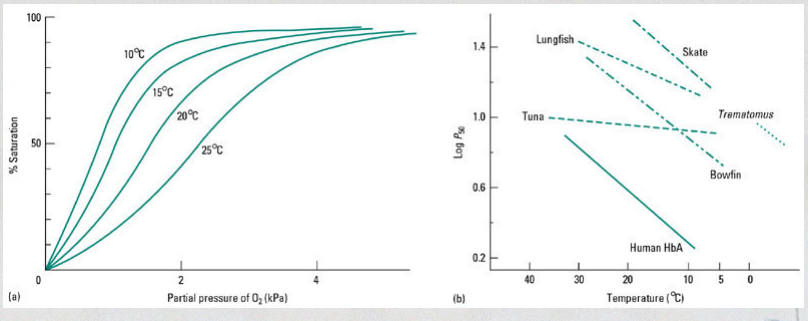
# Oxygen stores - blood

Temperature effects on $O_2$ dissociation curve

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# Oxygen stores - blood
# A-V peripheral distribution

Venous blood stores more oxygen than arterial blood because it has a much higher volume.

**Table 7.6** Properties of different kinds of blood vessels and distribution of blood in mammals (total volume = 8–9% body volume).

| | Typical diameter | Wall thickness | Composition of vessel wall (% diameter) | | | | % of total blood volume contained | |
|---|---|---|---|---|---|---|---|---|
| | | | Endothelium | Muscle | Collagen | Elastin | Systemic | Pulmonary |
| Aorta | 25 mm | 2 mm | 5 | 22 | 33 | 40 | – | – |
| Artery | 4 mm | 1 mm | 10 | 35 | 25 | 30 | 12 | 7 |
| Arteriole | 30 µm | 20 µm | 10 | 50 | 20 | 20 | | |
| Capillary | 8 µm | <1 µm | 100 | 0 | 0 | 0 | 11 | 1 |
| Venule | 20 µm | 2 µm | 40 | 10 | 40 | 10 | 41 | 14 |
| Vein | 20 mm | 1 mm | 8 | 32 | 40 | 20 | | |
| Heart | | | | | | | | 14 |

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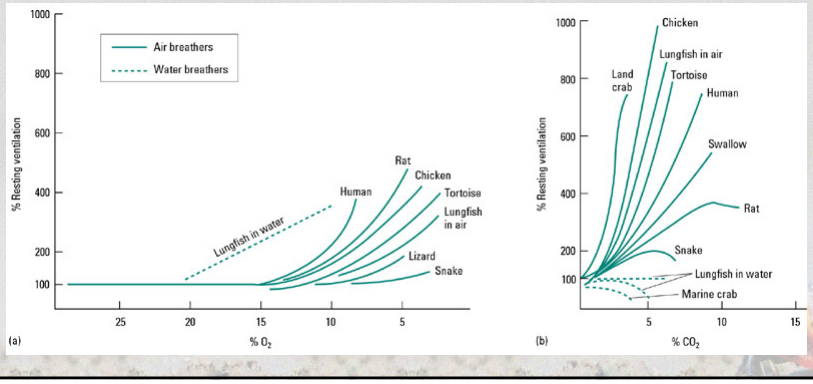
# Respiratory control

Aquatic animals, compared to terrestrial animals more often measure oxygen rather than $CO_2$

- because $pCO_2$ is low and solubility is high
- $O_2$ is relatively constant on land

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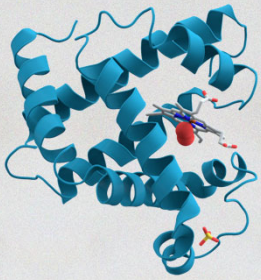
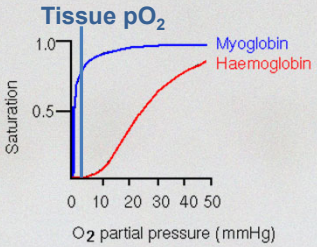
# Oxygen stores - muscle

Oxygen content of the muscle depends on myoglobin concentration - tissue $pO_2$



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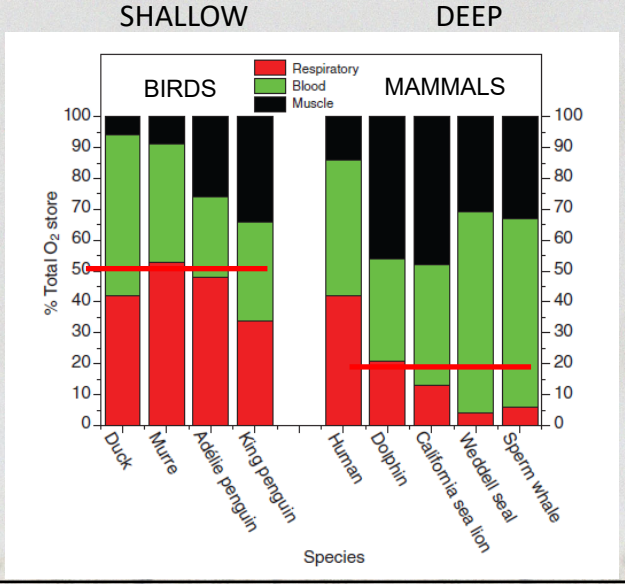
# Comparison of oxygen stores

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# Hydrostatic hyperbaria

Pressure increases under water:

| *Depth (feet)* | *Atmosphere(s)* |
|---|---|
| Sea level | 1 |
| 33 | 2 |
| 66 | 3 |
| 100 | 4 |
| 133 | 5 |
| 166 | 6 |
| 200 | 7 |
| 300 | 10 |
| 400 | 13 |
| 500 | 16 |

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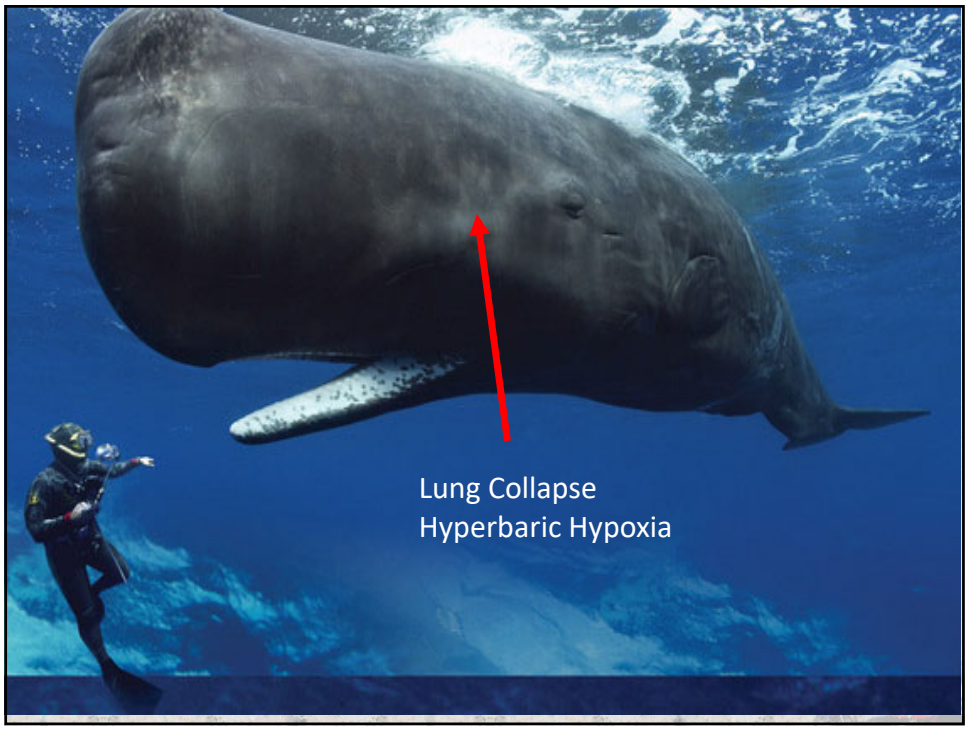


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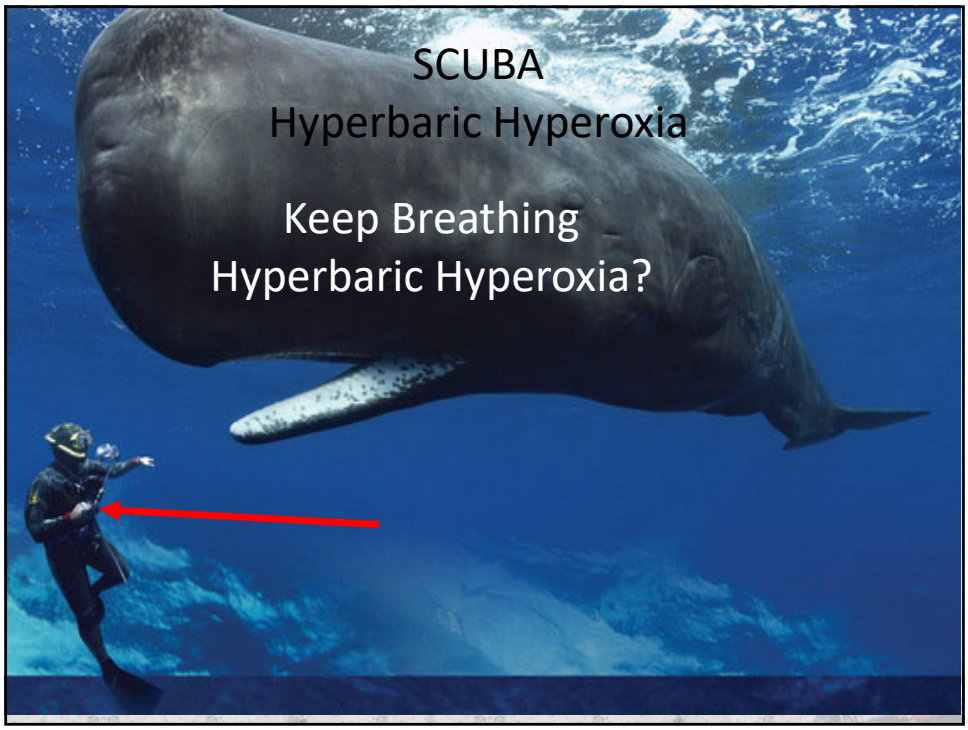


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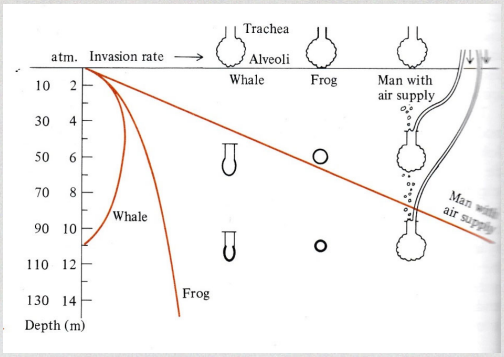
# Lung collapse and invasion rate

Invasion rate of gasses into blood

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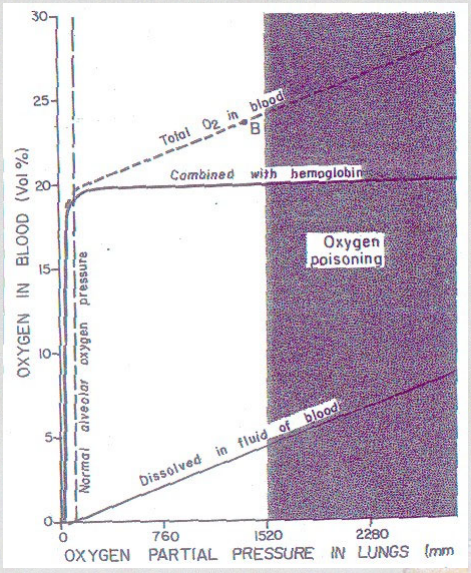
# Problems breathing air at high pressures

Higher partial pressures dissolve more gases in the blood, other body fluids, and fat.

Oxygen poisoning

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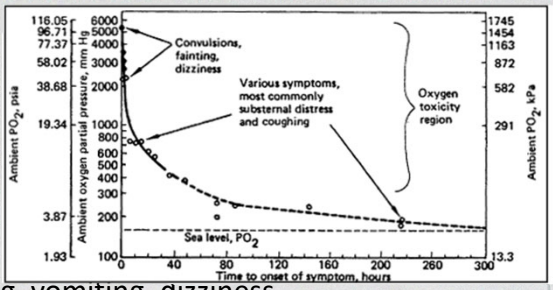
# Diving Hyperbaria

Oxygen toxicity:

Pulmonary effects ($pO_2$ > ~0.6 atm (1 atm=760 mm Hg)

- burning sensation on breathing
- coughing, pneumonia
- permanent lung tissue damage




CNS effects

- muscle twitching, vomiting, dizziness
- vision/hearing problems
- anxiety, confusion, irritability, seizures

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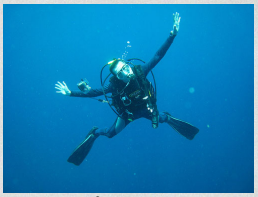
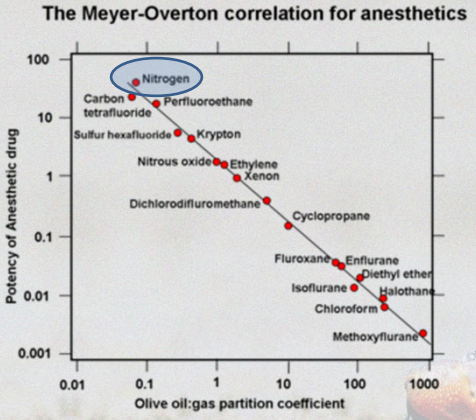
# Diving hyperbaria



Nitrogen narcosis:

"raptures of the deep" at > 200 m, NO-like narcosis

very high partial pressures of $N_2$ can cause nitrogen narcosis

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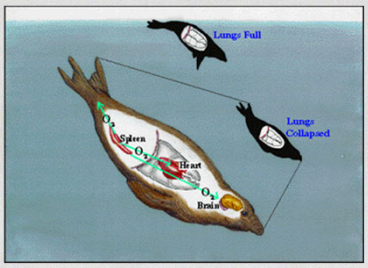
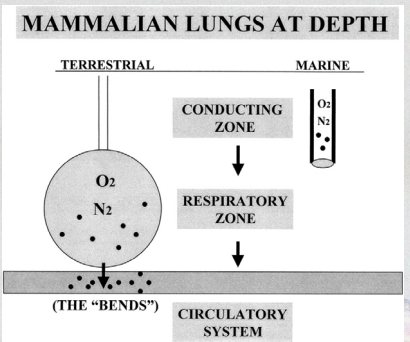
# Diving Response

Avoiding the bends – lung collapse

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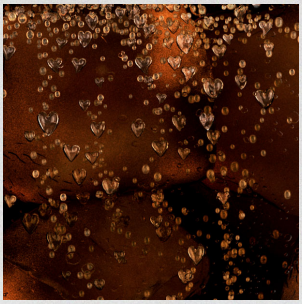
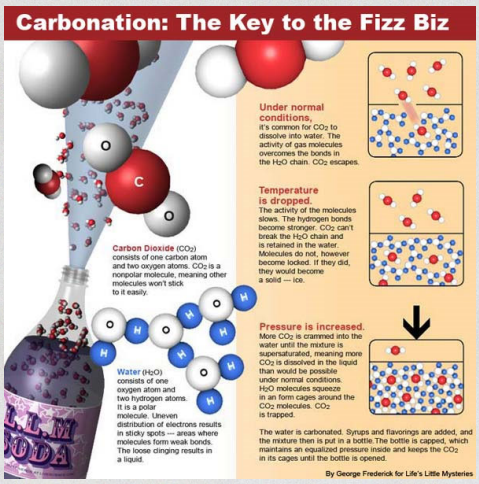
# The Soda Fizz




Carbonation: The Key to the Fizz Biz
Carbon Dioxide (CO2) consists of one carbon atom and two oxygen atoms. CO2 is a nonpolar molecule, meaning other molecules won't stick to it easily.
Water (H2O) consists of one oxygen atom and two hydrogen atoms. It is a polar molecule. Uneven distribution of electrons results in sticky spots — areas where molecules form weak bonds. The loose clinging results in a liquid.
Under normal conditions, it's common for CO2 to dissolve into water. The activity of gas molecules overcomes the bonds in the H2O chain. CO2 escapes.
Temperature is dropped. The activity of the molecules slows. The hydrogen bonds become stronger. CO2 can't break the H2O chain and is retained in the water. Molecules do not, however become locked. If they did, they would become a solid — ice.
Pressure is increased. More CO2 is crammed into the water until the mixture is supersaturated, meaning more CO2 is dissolved in the liquid than would be possible under normal conditions. H2O molecules squeeze in an form cages around the CO2 molecules. CO2 is trapped.
The water is carbonated. Syrups and flavorings are added, and the mixture then is put in a bottle.The bottle is capped, which maintains an equalized pressure inside and keeps the CO2 in its cages until the bottle is opened.
By George Frederick for Life's Little Mysteries

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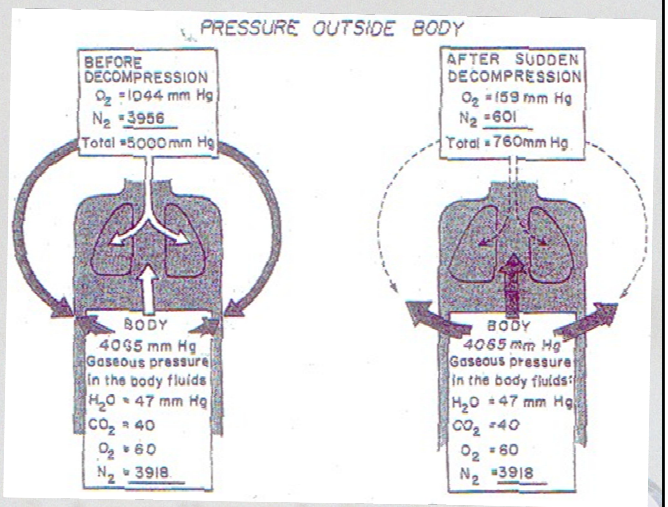
# High pressure can cause physiological problems, e.g. CAISSON DISEASE

when you depressurize, the extra dissolved gases can suddenly undissolve out of the body tissues, causing the "BENDS".

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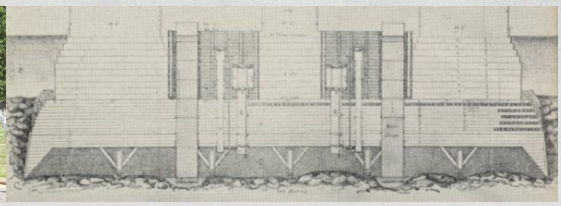
# CAISSON DISEASE (BENDS)

A caisson is a strengthened gun carriage, for carrying ammunition



A caisson is also a strengthened wooden box that is lowered under water and pressurized, so workers can work underwater

e.g. constructing the Brooklyn Bridge

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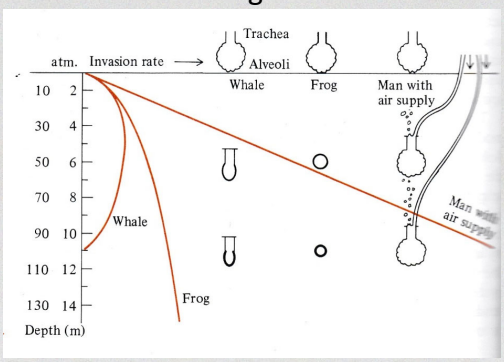
# So lung collapse is highly beneficial in deep diving animals

Invasion rate of gasses into blood

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One treatment for “bends” is to re-pressurise the person in a hyperbaric chamber